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# METHOD OF CONTROLLING FLOATING BODY EFFECTS IN AN ASYMMETRICAL SOI DEVICE

## DESCRIPTION

## BACKGROUND OF THE INVENTION

5 Field of the Invention

The present invention generally relates to semiconductor devices and integrated circuits formed on substrates containing an insulator layer such as silicon-on-insulator chip or wafer and, more particularly, to the control of floating body effects in transistors formed on such substrates.

## Description of the Prior Art

15 Demands for increased performance, functionality and manufacturing economy for integrated circuits have resulted in extreme integration density to reduce signal propagation time and increase noise immunity while increasing the number of circuits and devices that can be formed on a chip or wafer by a single sequence of processes. Scaling of devices to small sizes has also restricted operating margins and required increased uniformity of electrical characteristics of semiconductor devices on a chip.

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To satisfy this latter criterion, silicon-on-insulator (SOI) wafers have been used to exploit the improved quality of monocrystalline silicon provided

thereby in an active layer formed on an insulator over a bulk silicon "handling" substrate. Similar attributes can be developed in similar structures of other semiconductor materials and alloys thereof.

5 The improved quality of the semiconductor material of the active layer allows transistors and other devices to be scaled to extremely small sizes with good uniformity of electrical properties.

Unfortunately, the existence of the insulator 10 layer which supports the development of the improved quality of semiconductor material also presents a problem known in the art as floating body effect in transistor structures. The floating body effect is specific to transistors formed on substrates having 15 an insulator layer. The neutral floating body is electrically isolated by source/drain and halo extension regions that form oppositely poled diode junctions at the ends of the transistor conduction channel and floating body while the gate electrode 20 is insulated from the conduction channel through a dielectric. The insulator layer in the substrate completes insulation of the conduction channel and thus prevents discharge of any charge that may develop in the floating body. Charge injection into 25 the neutral body when the transistor is not conducting develops voltages in the conduction channel in accordance with the source and drain diode characteristics.

The voltage developed due to charge collection 30 in the transistor conduction channel has the effect of altering the switching threshold of the transistor. This effect, in turn, alters the signal

timing and signal propagation speed since any transistor will have a finite slew rate and the rise and fall time of signals is not instantaneous even when gate capacitance is very small. Therefore, the 5 diode characteristics of the source and drain must be tailored to limit charge build-up in the floating body.

To do so, the diode junctions must be made somewhat leaky to allow the floating body of the transistor to be discharged to an acceptable degree. Unfortunately, since field effect transistors are generally formed symmetrically with identical source and drain impurity structures, development of such a characteristic reduces the ratio of resistance of 10 the "on" and "off" states of the transistor, often referred to as the on/off ratio. A large on/off ratio is desirable to support maximum circuit fanout (the number of transistor gates, a transistor can drive with acceptable switching speed) and to 15 provide maximum signal voltage swing close to the power supply voltage. Therefore, there is a trade-off between limitation of floating body effects and maintaining a suitable on/off ratio.

While most known designs for field effect 20 transistors are symmetrical, asymmetrical FETs have been proposed and investigated by simulation, but possibly not realized, for reduction of short channel and hot carrier effects and/or suppression 25 of parasitic bipolar transistor effects (but not reduction of floating body effects), as reported, for example, in "An 0.1- $\mu$ m Asymmetric Halo by Large-Angle-Tilt Implant (AHLATI) MOSFET for High 30

Performance and Reliability" by . Shin et al., IEEE Transactions on Electron Devices, Vol. 46, No. 4, April 1999, and "A High Performance 0.1  $\mu$ m MOSFET with Asymmetric Channel Profile" by A. Hiroki et al. IEEE, 1995.

These approaches use angled implants which are asymmetrically placed due to shadowing by a (possibly dummy) gate structure and are largely characterized by substantial process complexity and diffusion of impurities over substantial distances which prevents the formation of sharp impurity concentration gradients and low precision of impurity structure placement. The proposed processes also do not provide for differences in impurity concentration between the source and drain but only differences in location. In summary, while some asymmetry is provided, the flexibility of design parameters in accordance with the proposed processes is very limited and, while source and drain characteristics may be made to differ somewhat, the diode characteristics cannot be accurately tailored or independently fabricated.

The approach to reduction of floating body effects at the present state of the art is to form a connection from the floating body/conduction channel to the source electrode through the impurity well. This approach is only a partial solution since the well can be highly resistive and the connection can be ineffective. Further, the connection requires additional chip space and therefore precludes achievement of the potential integration density that would otherwise be possible.

It is also known in fabrication of integrated circuits at very small feature size regimes to form conductive structures such as interconnects by a Damascene process; yielding structures of superior 5 stability, accuracy and other mechanical properties. A Damascene process involves formation of a recess at a surface, depositing metal in the recess and planarizing the deposited metal to the surface. This produces a conductive structure of very precise 10 dimensions and which is laterally supported at all times and is therefore particularly resistant to metal migration and damage in interconnect structures.

More recently, in an effort to achieve higher 15 conductivity of gate structures, metal gates have been developed and a Damascene process has been proposed for fabrication of the same, as reported in, for example, "Damascene-Gate Thin Film Transistors with Ultra-Thin Gate Dielectrics" by E. 20 Ma et al., IEEE 1998. However, process complexity is substantial and, moreover, metal gate transistors have been found to present difficulties in obtaining a desired work function difference between NMOS and PMOS devices.

25 A Damascene gate can also be used to allow formation of the gate dielectric and gate electrode subsequent to source and drain implantation with a dummy gate as reported in "Plasma Damage Free Gate Process Using Chemical Mechanical Polishing for 0.1 30  $\mu\text{m}$  MOSFETs" by T. Saito et al., Japanese Journal of Applied Physics; April, 1999. However, since a dummy gate structure is used for source/drain

implantation, substantial process complexity is required to obtain correct gate structure registration and the Damascene process must be performed after the source/drain implantation processes are complete. Moreover, use of a dummy gate structure cannot serve to increase location accuracy or concentration gradient of impurity structures such as halo and extension implants as discussed above.

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## SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a method of fabricating a transistor on a SOI substrate which can be made substantially free of floating body effects by allowing tailoring of diode characteristics of the source and/or drain of the transistor.

It is another object of the invention to provide a simplified process for fabrication of an asymmetric field effect transistor which provides improved accuracy of location and concentration gradient of impurity structures for improved performance.

In order to accomplish these and other objects of the invention, a method of forming an asymmetric field effect transistor to control floating body effect and a transistor having reduced or eliminated floating body effects formed by such a process is provided wherein the method or process includes steps of defining a gate location with a trench in a dielectric layer on a semiconductor layer, supplying impurities to the semiconductor layer at edges of the trench and adjacent source and drain regions, and forming a gate structure on the semiconductor layer in the trench. The impurities are supplied by angled implantation and/or diffusion from a doped solid body formed in the trench to accurately locate desired impurities such that diffusion is not required to drive the impurities to a desired location; thus supporting steep impurity concentration gradients and high performance.

## BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, aspects and advantages will be better understood from the following detailed description of a preferred embodiment of the invention with reference to the drawings, in which:

5 Figures 1, 2, 3 and 4 are cross-sectional views illustrating basic principles of the invention,

10 Figures 5, 6, 7, 8, 9 and 10 are cross-sectional views illustrating fabrication of a preferred embodiment of the invention, and

15 Figures 11, 12, 13, 14, 15, 16 and 17 are cross-sectional views illustrating an alternative method of fabricating the preferred embodiment of the invention and variations thereof.

DETAILED DESCRIPTION OF A PREFERRED  
EMBODIMENT OF THE INVENTION

Referring now to the drawings, and more particularly to Figures 1 - 4, there is shown, in cross-section, sequential stages in the fabrication of a transistor in accordance with the invention and illustrating the basic principles of the invention in satisfying the above-noted and other objects.

5 Figure 1 shows the surface of a semiconductor substrate or other layer 12 with a patterned thick oxide layer 14 formed thereon. The patterning includes a trench or aperture 16 which is preferably formed lithographically using any suitable lithographic tool and process and is preferably of the desired final dimensions of the transistor gate.

10 Deep ultra-violet or electron beam exposure is generally required for exposing features of current and foreseeable sizes where the advantages of the present invention are most evident. However, it should be understood that the invention may be

15 applied to form transistors of any desired dimensions.

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A basic principle of the invention is illustrated in Figure 2. Using the trench structure of Figure 1 rather than a gate structure as in the publications cited above, angled implants such as 22 and/or 24 may be made in sequence. The angle, generally in the range of 20° to 35° should be chosen in consideration of trench dimensions so that the shadow of the trench or aperture walls 18 expose only a desired relatively narrow region at the

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bottom of the trench 16. Angled implants 22 and/or 24 can be repeated at the same or different angles with impurities of the same or different conductivity type and appropriate energies to form 5 extension, halo or any other type of impurity structure that may yield desired conduction properties in connection with dimensions, materials and other parameters of the transistor design.

It should be appreciated that the locations 10 exposed by the shadow of walls 18 will be the locations generally desired for impurity structures which enhance or determine the conduction properties of the transistor channel which is exposed by the patterning 16 of the oxide 14. Therefore, the 15 impurities can be directly implanted in the semiconductor layer 12 at precisely the desired location. The process is not complicated by implanting through another layer and the annealing process which follows the implantation can be 20 limited to a heat treatment sufficient to activate the impurity and repair lattice damage but produce little, if any, diffusion. Therefore, impurity concentration gradients may be maintained and located with high accuracy and uniformity.

It should also be appreciated that angled 25 implants 22 and 24 and any repetitions thereof are also completely decoupled from each other and independent. Therefore, the diode properties at the source and drain may be established independently, 30 asymmetrically and with complete design flexibility. Further, except for changes of angle, energy and impurity type(s) the angled implant processes are

identical and therefore do not significantly complicate the overall process and may serve to simplify the process relative to other possible alternatives while producing a transistor with 5 potentially enhanced performance with improved reliability and yield as well as improved uniformity.

As shown in Figure 3, the gate structure is completed by growing or depositing a gate dielectric 10 32 which may be oxide, nitride, composite and/or layered materials or high dielectric constant materials. The gate electrode 34 may then be deposited and planarized back to the surface 36 of oxide 14. The gate material may be either metal 15 or doped polysilicon or other materials that will be evident to those skilled in the art. It should be noted that the structure shown in Figure 3 is similar to a Damascene gate and oxide 14 could be left in place to form a Damascene gate if the source 20 and drain implants had been done previously. However, this is not preferred since accuracy of the impurity structures could be compromised and other processes are available to obtain Damascene or 25 quasi-Damascene gate structures if desired. (The term "quasi-Damascene" is used to denote structures which have the appearance of Damascene structures which may be formed in a recess as in a true Damascene process but where the final lateral 30 support for the structure is provided after formation of the structure.)

The transistor is then completed by removal of oxide 14 and performing the drain and source

implants as indicated at 42. A passivation layer of oxide or other insulator may then be applied to substantially complete the transistor. A thick oxide layer could be applied and planarized back to 5 the gate 34 to yield a quasi-Damacene gate structure.

It should be noted that the process discussed above in connection with Figures 1 - 4 can be performed and the structure fabricated on any 10 substrate, regardless of composition or construction. While the principal presently contemplated meritorious effects are directed to the avoidance of floating body effects in structures formed on an SOI substrate by allowing independent 15 formation and tailoring of source and drain impurity structures such as halo and extension structures, such a capability of decoupling source and drain processing and other meritorious effects, such as developing of sharp impurity concentration gradients 20 may be useful in other environments such as on substrates of silicon or other materials and which may or may not include an insulator or other structures. Therefore, it is intended that Figures 25 1 - 4 which illustrate the basic principles of the invention be understood as comprehending such other environments.

Referring now to Figures 5 - 10 a preferred embodiment of the invention will now be discussed. This process closely follows the process discussed 30 above in connection with Figures 1 - 4 and discussion of portions the process of Figures 5 - 10 which are common to the generalized process of

Figures 1 - 4 will be abbreviated or omitted.

Figure 5 shows a cross-sectional view of an exemplary SOI wafer 52. Layer 54 is generally referred to as a handling substrate since, in general, its principal function is to provide mechanical support for insulator 56 and active silicon layer 58. However, it is known to form various structures thereon or therein to use the handling layer 54 as a heat sink, an electrically active device, a passive electronic region such as shielding or a ground plane and the like. Multiple pairs of insulator and active or passive silicon layers can also be included, as desired.

As shown in Figure 6, a thick dielectric film 62 is deposited and patterned to form a trench 64 to the active silicon layer 58. Then, as shown in Figure 7, an angled implant 72 is performed to form an extension and/or halo structure 74 on the source side. These structures can be formed concurrently or sequentially at the same or different implant angles and energies; the location being determined by the implant angle and the shadow formed by thick oxide 62 within aperture 64. Similarly, as shown in Figure 8, halo and/or implant structures 84 are formed concurrently or sequentially by angled implants 82 at the drain side. The process illustrated in Figure 8 may precede or follow that of Figure 7 or sequential parts of both can be interleaved in any desired manner. In any case or order of processes or partial processes, including annealing for impurity activation and/or annealing which can be performed after any implant, the

formation of impurity structures at the source and drain sides of the transistor are completely decoupled and the diode junction at either or both sides can be tailored precisely as desired.

5        Then, as shown in Figures 9 and 10, the gate oxide or other gate insulator 92 can be deposited or grown and gate electrode 94 formed. Then, if source and drain regions have not been previously formed, thick oxide 62 can be removed and implants  
10      performed, followed by a final annealing process, as described above. The transistor is then completed using known processes as may be desired.

15      Figures 11 - 17 show a variant method for forming transistors in accordance with the invention. It should be understood that the principles of this variant method can be used in substitution for any portion or the entirety of the process discussed above in regard to Figures 7 and 8 and has the potential for developing different  
20      impurity distributions and/or concentration gradients than may be produced from the embodiment of Figures 5 - 10. In this regard, the embodiment of Figures 11 - 17 should be understood as illustrating a basic alternative principle of the  
25      invention that any or all angled implant(s) as described above can be replaced by diffusion from a solid body for any purpose addressed by the invention while maintaining the novel decoupling of formation of source and drain impurity structures.

30      Starting with a wafer or wafer structure as illustrated in Figure 1 or 5, Figure 11 illustrates deposition of a thin oxide layer 1102. The

thickness is not critical to the basic principles of the invention but should be chosen in connection with the width of sidewall which is to be formed in accordance with a given design in the trench 1202 5 patterned into the thin oxide (or other material) 1102, as shown in Figure 12. A conformal layer of doped material such as an oxide is deposited thereon and anisotropically etched to form sidewalls. The thickness of the doped material layer should also be chosen in accordance with the width of sidewall to 10 be developed as is well-understood in the art. These processes result in symmetrically formed spacers 1302 of doped material as illustrated in Figure 13.

15 Then, as shown in Figure 14, a resist is applied, exposed developed and thus patterned to cover only one of spacers 1302. Registration may be somewhat critical for devices of small minimum feature size but it should be appreciated that the 20 process window for exposure and registration of the mask edge is only slightly smaller than the minimum feature size and thus necessarily within the capacity of the exposure tool capable of other processes at similar resolution. One of spacers 25 1302 is thus removed by selectively etching while the other is protected by the resist, as shown in Figure 15; after which dopant can be outdiffused from the remaining spacer solid body to form impurity structure 1502.

30 The process of Figures 12 - 14 can then be repeated using a differently doped material, with or without removal of spacer 1302 to form spacers 1602

as shown in Figure 16 and one of the spacers 1602 can be removed by masking and etching, if desired, as shown in Figure 17. Diffusion annealing can be performed immediately or combined with a later heat treatment, as may be desired or dictated by the device design. The spacers/diffusion sources can then be removed and the device completed as discussed above in connection with Figures 9 and 10.

In view of the foregoing, it is seen that the invention provides two techniques which may be used alternatively or in combination to decouple the formation of impurity structures at different locations in a semiconductor device such as a field effect transistor so that the diode characteristics thereof may be individually and accurately tailored for any desired purpose such as avoiding floating body effects when SOI substrates are employed for the formation of such transistors. The invention also provides a much simplified and accurate process for forming asymmetric transistors having high performance structures therein and which supports accurate location of impurity structure profiles and steep impurity concentration gradients.

While the invention has been described in terms of a single preferred embodiment, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the appended claims.